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DAMPING OF LOW FREQUENCY OSCILLATION USING COORDINATED CONTROL STRATEGY OF PI AND UPFC DEVICES

M. DILIP KUMAR[1] & P. SUJATHA[2]

[1]*Associate Professor, Department of EEE, Priyadarshini Institute of Technology, Tirupati, Andhra Pradesh, India*

[2]*Professor, Department of EEE, JNTU College of Engineering, JNTUA, Ananthapur, Andhra Pradesh, India*

ABSTRACT

Rapid growth of Indian economy has stirred a tremendous need for power and has resulted in operation of power infrastructure to their limits. One important impediment in operating the power infrastructure at their maximum operating point is low-frequency electromechanical oscillations typically in the range of 0.1–0.8 Hz. This paper elaborates a scheme for damping these oscillations using combination of PI and UPFC device. The results of the proposed approach are validated for a 3-machine 9-Bus WSCC test power system.

KEYWORDS: Indian Economy, Infrastructure, Oscillations & Power System

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Original Article

INTRODUCTION

There is an imbalance between the increasing generation capacity and corresponding growth of transmission infrastructure. India doesn't have necessary transmission infrastructure to have evacuate all the generated power existing transmission lines should be utilized to a maximum capacity by loading them closer to their limits. The existing power systems are complex highly interconnected and evolve almost on a daily basis. Some of the major issues experienced by the present transmission system include the need for reactive power compensation system, problems related to voltage stability and power system. Oscillations owing to faults and sudden load disturbances, one of the important tasks of a power system engineers is to enhance the reliability and efficiency of the existing system. In order to have operational reliability and financial profitability the power system infrastructure needs proper utilization and control. FACTS devices through their advanced technology can provide effective utilization of the existing power systems and enhance their stability and performance. One of the major concerns, then, is secure operation of the system because of the presence of low-frequency electromechanical oscillations typically in the range of 0.1–0.8 Hz. One primary way of tackling the problem is to improve the dynamic behavior of the system and thereby allowing system operation closer to the capacity, without compromising security.

Traditional ways of tackling the problem is getting increasingly complex because of variety of reasons including the lack of accurate information for all the components required to model the entire power system.

It is increasingly difficult to get accurate information about overall performance of the system as there are different independent power producers, different utilities and increased interconnection between systems. One typical issue that is inherent to the interconnected synchronous generators is the phenomenon of electromechanical oscillations. Stabilization of these electromechanical oscillations is a very important necessity to have stable and

secure operation. Those oscillations that are association with single generator or a single plant are referred to as local mode oscillations or plant mode oscillations. The characteristics of local mode oscillations are well understood and have typical frequencies in the range of 0.7HZ - 2.0HZ [1].Those oscillations that are attributed to a group of generators or group of plants are referred to as inter-area mode oscillations. The characteristic of inter area mode oscillations are not fully understood and the factors influencing them are not completely identified. These inter area mode oscillations typically have frequency in the range of 0.1HZ - 0.8HZ [1].Electro-mechanical oscillations are usually studied through model analysis of linearised system model. Considering the criticality of the problem alternate analysis techniques have to be developed the multiple number of studies have shown. The successful use of supplementary control signals, the use of governor systems can improve the dynamic performance of a system this dynamic performance is brought about by providing extra damping through supplementary control signals. Power systems are highly non-linear and typically operate over wide range. Regularly the power systems are subjected to random changes in load which can result in a white noise disturbance. In order to have satisfactory control over the performance it's preferable to have a stabilizer that can adjust its own parameters and adapt its structure online. Power system stabilizers (PSS) which are usually installed at generator locations or localized stabilizers are typically suited only for damping local mode of oscillations. On the other hand inter area mode oscillations are associated with inter connected power systems and hence suitable damping control methodologies should be evolved. The issues related to voltage stability and reactive power compensation can be typically dealt by conventional PI controllers. On the other hand it is difficult to damp the inter harmonic oscillations with the help of conventional controllers. Apart from their inability to damp these oscillations these PI controllers can also reduce and increase these oscillations in some system.

This paper discusses a scheme for power system oscillations damping using a PI controller in unison with a UPFC device.

LITERATURE REVIEW

Different modes of oscillations exist in power systems due to interaction among various components mostly these oscillations are resultant of synchronous generators rotors swinging relative to each other. when a system is stressed it is known to exhibit non-linear behavior. Abrupt changes in load and occurrence of faults are the primary reasons for power oscillations. if these oscillations are not properly contained they can result in total or partial outage of the system, if the oscillations are not done properly they may sustained and grow eventually caucusing the system fail [3].There are different methods reported in literature for damping these oscillations and one of the most common methods is to install power system stabilizer(PSS) on generators [4-8].Even though power system stabilizer can enhance stability and damp oscillations there are limitations in determining the optimum value of PSS parameters. Improper selection of values can result in inadequate damping resulting power system instability. It is imperative to have proper selection of values and since 1981 several approaches have been identified and presented for determining the PSS control parameters. These methods include artificial neural networks, pole placement, adaptive control and variable structure control based on model control theory [9-15]. Over the years PSS have been widely utilized by power utilities to enhance system stabilities and to reduce inter- harmonics oscillations, however years of operation result in problems and also PSS have limited ability to damp only local oscillations and not inter harmonic oscillations. Another typical issues related to the use of PSS is its ability in causing severe variations in voltage profile under sudden changes of load. This may result in the system loosing stability because of loading power factor operations. Recently the concept of FACTS devices have been considered widely

in power system operational and control, these FACTS devices have opened new opportunities for controlling the power and enhancing useable capacity of existing transmission lines. One of the important applications of FACTS devices is in the control of inter-harmonic oscillations, in such an approach a supplementary control is usually needed in the one of the control loops [16-18].FACTS controllers have many advantages like their ability to provide effective line impedance, angle control and uniform application for transmission voltage. They also provide independently controllable reactive power compensation and have a unique potential to exchange real power directly with the AC system. Typically UPFC as a solid state controller finds several references in technical literatures [19-24].they present different things among basic operation of UPFC its modeling and control [22-24].

MODELING OF UPFC AND PI CONTROL SCHEME

Of the many FACTS devices available UPFC is one of the most important FACTS devices. It's flexible and has multifunctional abilities it can perform bus voltage control by providing shunt reactive current injection and power flow control by injecting series reactive voltage in transmission line. The UPFC cannot damp oscillations effectively if it is operated manually or controlled by improperly tuned PI controller thus cannot damp inter-harmonic oscillations. In order to achieve this it is essential to have oscillation damping control, stability loop or an auxiliary controller

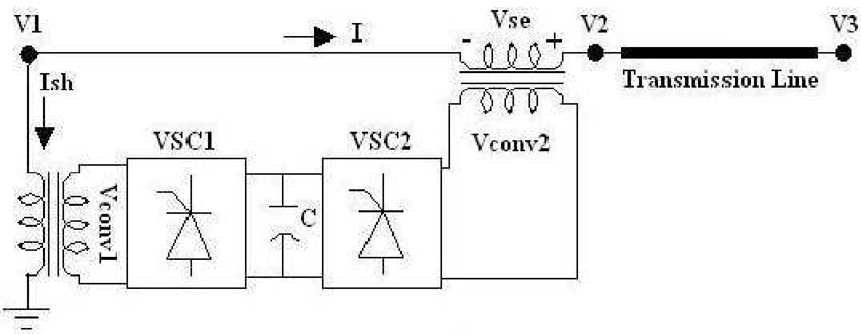

Figure 1: The Scheme of UPFC

The basic block diagram of UPFC is shown in the figure1. It can be observed from the figure it has two back to back AC to DC synchronous voltage source converter [VSC1 and VSC2].which are operated through a common dc link capacitor [23,28,29]. A shunt connected transformer which helps in connecting VSC1 in shunt while a series connected transformer connects VSC2 in series. The important elements of UPFC's shunt branch include a dc capacitor, VSC1 and a shunt connected transformer which corresponds to a STATCOM. This has the capability to absorb or a generate only reactive power because the output current his in quadrature with terminal voltage. On the other hand the series branch of UPFC has a DC capacitor VSC2 and series connected transformer corresponding to an SSSC. This series component his capable of acting as a voltage source, in which the voltage is injected in to the transmission line with the help of a series connected transformer.

It is obvious that two branches of UPFC can absorb or generate reactive power independent of each other when the two converters VSC1 and VSC2 are operating on the same time the series and shunt branches can function as an ideal AC to AC converter. In this converter the real power can flow either in direction through the dc link and between the AC terminals of the two converters. UPFC has a capability to introduce positive or negative phase shifts between V1 and V2.Three parameters have to be simultaneously controlled in the case of UPFC injection model these are shunt reactive power Q_{conv1} and the magnitude r and the angle γ,of injected series voltage $V_{se.}$ Figure 2 shows the circuit representation of

a UPFC, where the series connected voltage source is modeled by an ideal series voltage which is controllable in magnitude and phase and the shunt converter is modeled as an ideal shunt current source.

$$\overline{I_{sh}} = \overline{I_t} + \overline{I_q} \quad [1]$$

$$= (I_t + jI_q)e^{je}$$

The apparent power supplied by the series voltage source converter is calculated from

$$\bar{S}_{conv2} = Vse\overline{I_{se}}^{*}.\frac{-V_i - V_j}{jx_s}$$

$$= re^{jv}V_i \quad [2]$$

Active and reactive power supplied by Converter 2 are distinguished as

$$P_{conv2} = rb_s V_i V_j \sin(q_i - q_j + g) - rb_s V^2{}_i \sin g \quad [3]$$

$$Q_{conv2} = rh_s V_i V_j \cos(qi - qj + g) + rb_s V^2{}_i \cos g \quad [4]$$

$$l_t = -rb_s V_i V_j \sin(qi - qj + g) + rb_s V_i \sin g \quad [5]$$

The current of the shunt source is then given by,

$$\overline{I_{sh}} = (I_t + jI_q)e^{iqi} \quad [6]$$

The bus current injections can be defined as:

$$\overline{I_i} = \overline{I_{sh}} - \overline{I_{inj}} \quad [7]$$

$$\overline{I_j} = \overline{I_{inj}} \quad [8]$$

Where,

$$I_{inj} = -jb_s V_{se} \quad [9]$$

$$= -jb_s rV_{ie}{}^{iv}$$

Substituting 2 and 3 into 4 and 5 gives

$$I_i = (-ebsVj\sin(qij + g) + rbsV_i \sin g + jI_q)ejqi + jrbsV_{iej}(q_i + g) \quad [10]$$

$$I_j = -jbsViej(qi + g) \quad [11]$$

Besides the expressions for current bus injection, due to the control purposes, it is very useful to have expressions for power flows from both sides of the UPFC injection model defined. At the UPFC shunt side, the active and reactive power flows are given as:

$$P_{i1} = -rb_s V_i V_j \sin(\theta_{ij} + y) - b_s V_i V_j \sin(\theta_{ij}) \qquad [12]$$

$$Q_{i2} = rb_s V_i V_j \cos(\theta_{ij} + \Upsilon) - b_s V^2 + b_s V_i V_j \cos\theta_{ij} \qquad [13]$$

Whereas at the series side they are

$$P_{i1} = -rb_s V_i V_j \sin(\theta_{ij} + y) - b_s V_i V_j \sin(\theta_{ij}) \qquad [14]$$

$$Q_{i2} = rb_s V_i V_j \cos(\theta_{ij} + \Upsilon) - b_s V^2 + b_s V_i V_j \cos\theta_{ij} \qquad [15]$$

It can be identified from the previous equations that the UPFC current injection model is defined by bus current injection I_i and I_j. In addition to this the branch susceptance is also included in a model through the system bus admittance matrix. In order to have a control objective the parameters r,γ and Iq have to be suitably adjusted. In the case of power flow control the control variable I_q his irrelevant and UPFC performs the function of series compensator the control objective here his to maintained the power after control line at expected value. This implies that the UPFC must operate in the automatic power control mode to maintain the active and the reactive power flow at specific values of P_f and Q_f.

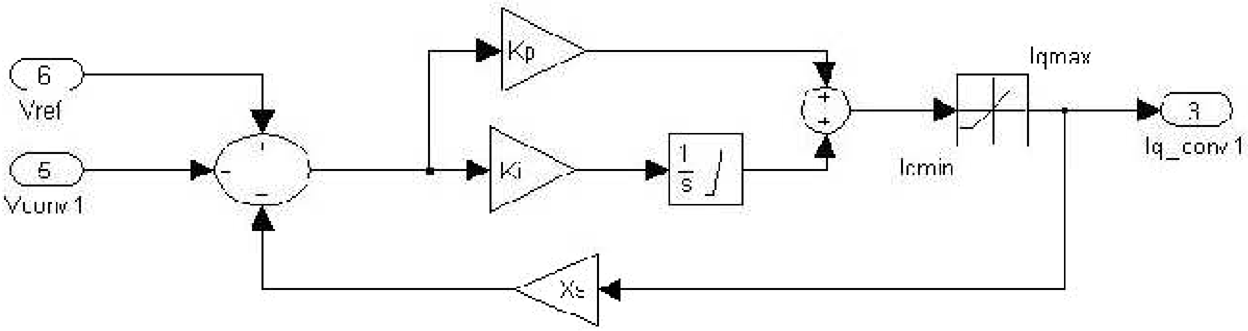

Figure 2: PI Voltage Controller Block Diagram of UPFC Shunt Converter

The SIMULINK model for PI Power Flow controller of series converter block diagram is shown in Figure 3. This controller gives appropriate series injected voltage for appropriate change in line power with respect to the reference power.

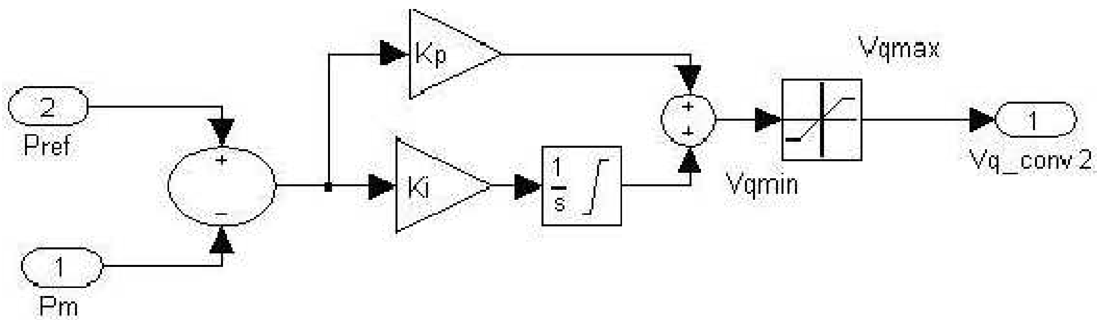

Figure 3: PI Power Flow Controller Block Diagram of UPFC Series Converter

THE TEST SYSTEM

The WSCC 3-machine, 9-bus system, is well-known as P.M Anderson 9-bus. It contains 3 generators, 6 lines, 3 loads and 3 two winding power transformers. Data is obtained from (26)

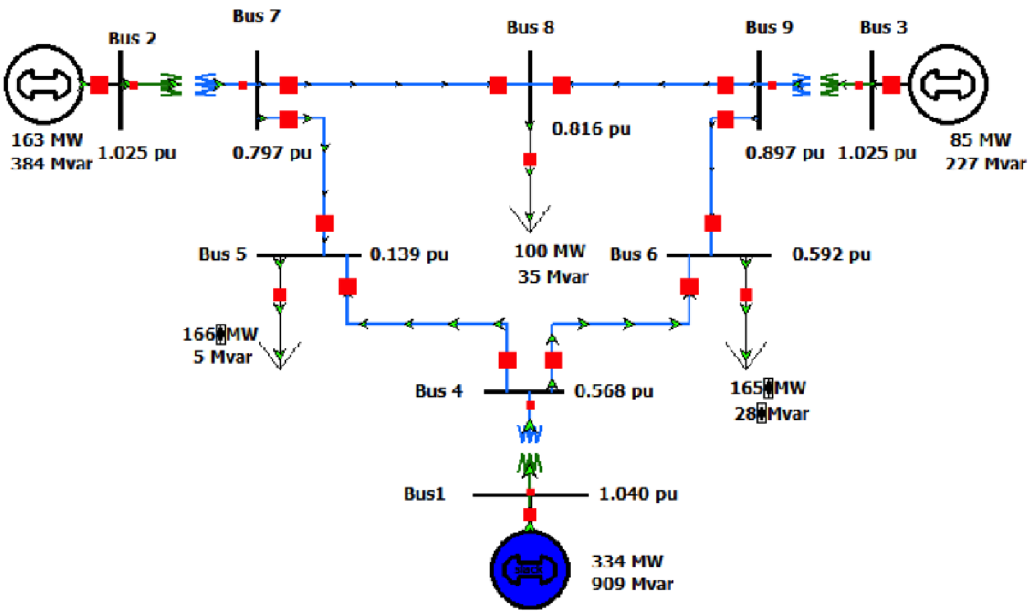

Figure 4: 3-Machine 9-Bus WSCC Test Power System Single Line Diagram

SIMULINK model for 3-machine 9-Bus WSCC test power system as shown in Figure 5 is developed with the help of the SIMULINK power system components.

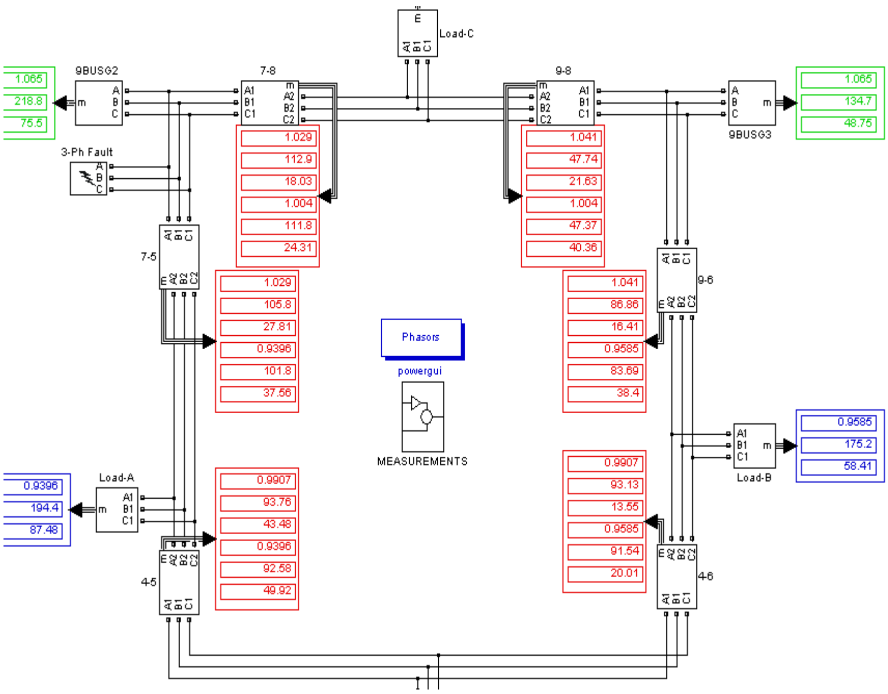

Figure 5: SIMULINK Model for 3-Machine 9-Bus WSCC Test Power System

RESULTS AND DISCUSSIONS

The UPFC is placed in transmission line 7 –5 in 3-Machine 9-Bus WSCC power system. The dynamic performance of UPFC with a step variation of Pref = [1 1.1 1] pu at time t = [0 15 25] at Vref = 1. Up to t = 1sec UPFC series element is bypassed so actual power flow in the line i.e., 0.8419 pu. For transient stability analysis 3-Ph short circuit fault at bus –7 at time t = 1sec and cleared at t = 1.1sec is considered and UPFC series element is bypassed up to t = 0.5sec.

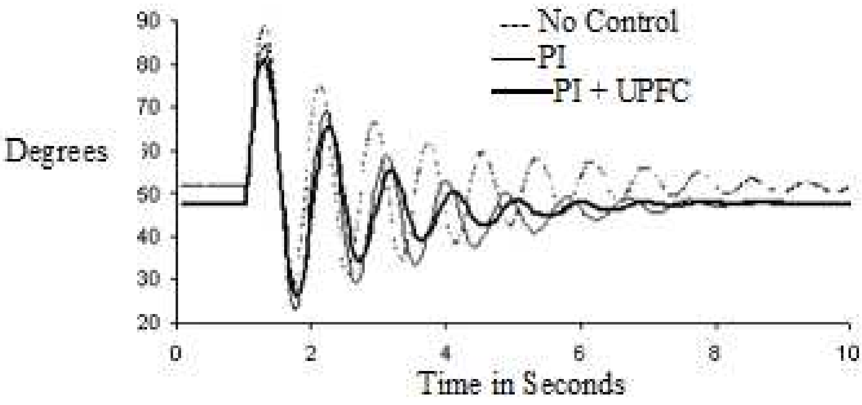

Figure 6: Rotor Angle Oscillations of Generator 2 with Respect to Generator 1 for 3-Ph Short Circuit at Bus – 7

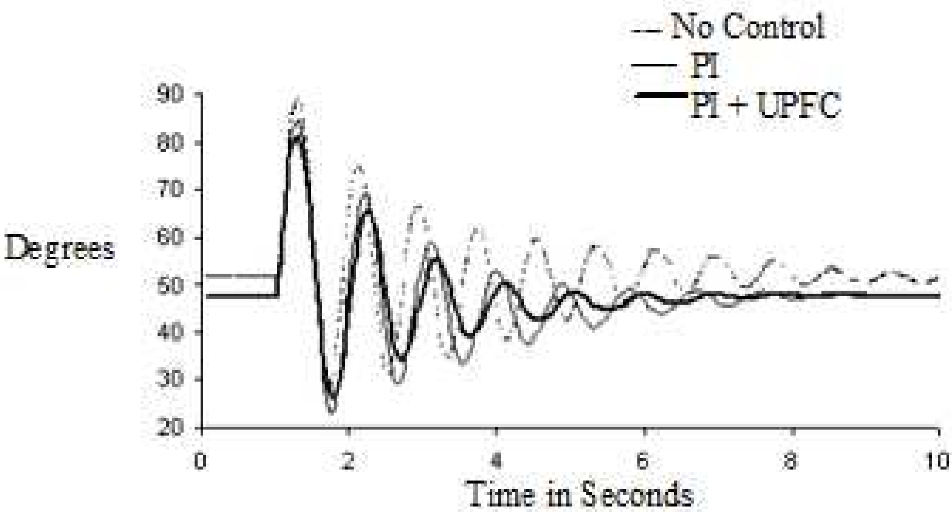

Figure 7: Rotor angle Oscillations of Generator 3 with Respect to Generator 1 for 3-Ph Short Circuit at Bus – 7

The Figure 6 and Figure 7 shows the rotor angle oscillations of generator-2 and generator-3 with respect to generator-1 of 3-Machine 9-Bus WSCC power system for 3 – Phase short circuit fault at bus – 7. The fault exists for the duration of 0.1 sec. These plots show the rotor angle oscillations with and without the presence of the UPFC in the system. It is obvious from these Figures that UPFC with proposed controller damps the oscillations considerably

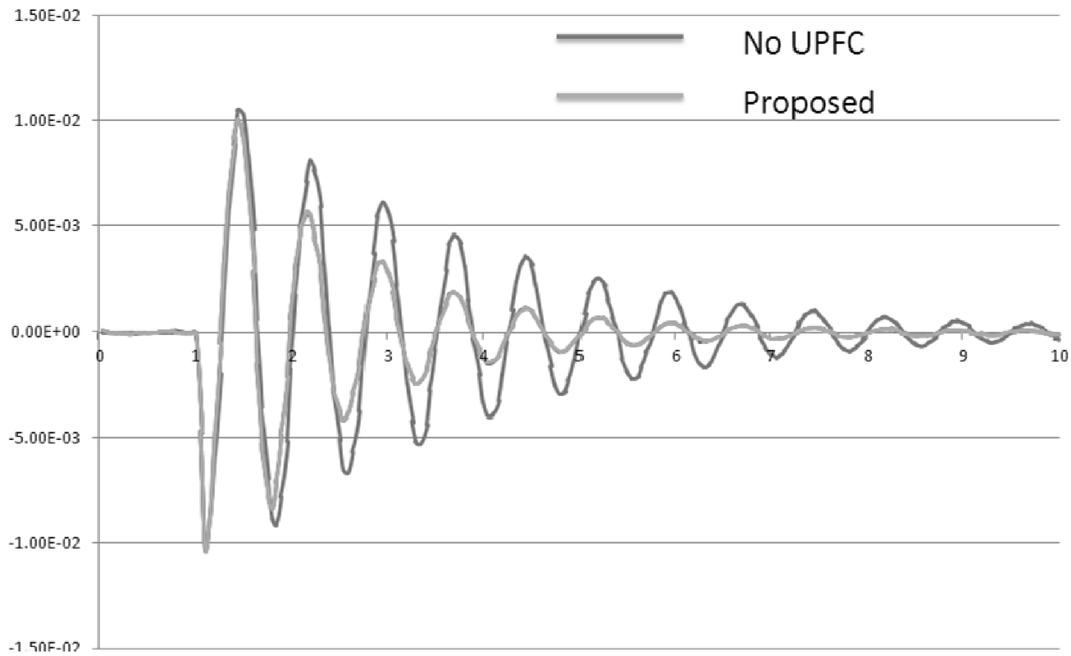

Figure 8: Oscillations for Machine 1- Comparison between No UPFC and Proposed- for 65 % Increase in Base Load

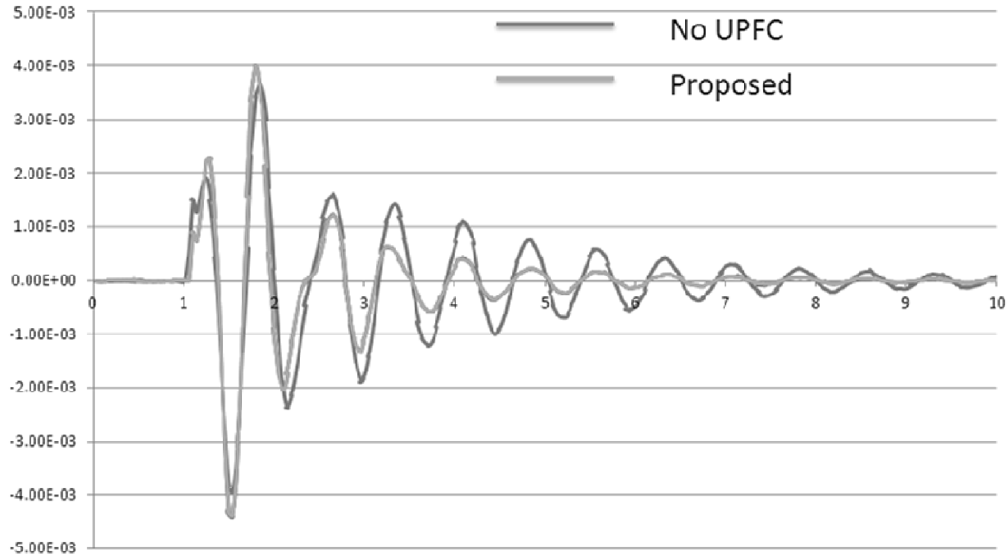

Figure 9: Oscillations for Machine 2- Comparison between No UPFC and Proposed- for 65 % Increase in Base Load

The figures (7-9 shows the power oscillations of generator-1, generator-2, generator-3 and power variation through transmission line 7-5 of 3-Machine 9-Bus WSCC power system for 3 – Phase short circuit fault at bus – 7 and subsequently when the load is also increased by 65 %.From these Figures, Without UPFC the power oscillations take more than 10sec to settling down. UPFC with proposed controller in the system power oscillations settle down to final steady value in less than 7 sec. UPFC with proposed controller damps the power oscillations effectively.

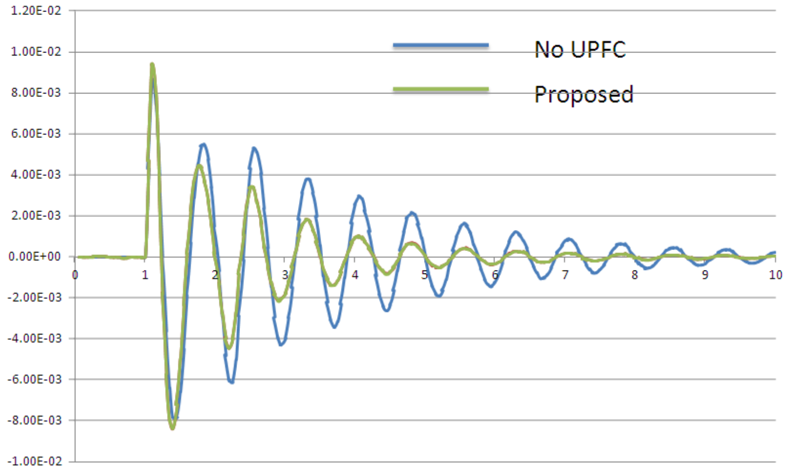

Figure 10: Oscillations for Machine 3- Comparison between No UPFC and Proposed- for 65 % increase in base load

CONCLUSIONS

In this paper, the SIMULINK models for 3-Machine 9-bus WSCC with dynamic exciters are developed. The SIMULINK model for UPFC with PI for damping inter harmonic oscillation is proposed. It can be concluded that the UPFC device give good performance to damp rotor angle and power oscillations with proposed controller.

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